Effectiveness of intermittent electrical stimulation for the prevention of deep pressure ulcers

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Abstract

Pressure ulcers are a common medical complication associated with individuals who, due to injury or disease have compromised mobility and/or sensation.

Pressure ulcers that start at the bone-muscle interfaces are the most perilous, as they can cause extensive damage to the deep tissue layers before exhibiting any signs in the skin. Lack of oxygenation to the tissue and the cascade of metabolic changes that follow, as well as mechanical deformation due to the compression of tissues are the main cause for deep ulcers.

We tested the effectiveness of intermittent electrical stimulation (IES) in preventing the formation of deep pressure ulcers in 3 groups of 6 rats each. Pressure equivalent to 38% of the bodyweight of each rat was applied to the quadriceps muscles from one limb of every rat. Two of the groups received IES to the same limb every 10 and 5 minutes respectively, throughout the application of pressure. The third group was utilized as a control.

Our results showed that electrical stimulation applied intermittently to muscles exposed to constant pressure reduces significantly the amount of damage in the muscles. This outcome provides an encouraging initial step in the development of an alternative method for pressure ulcer prevention.

1. INTRODUCTION

A pressure ulcer is a lesion involving damage to the skin, fat, muscle, and bone of body regions subjected to high pressures due to the prolonged compression of the soft tissue between a bony prominence and a surface.

Ulcer development can start at the skin level as a result of shear, friction and/or poor hygiene[1] and progress to encompass the underlying layers of tissue. More dangerously, it can also start in the deep tissue at bone-muscle interfaces, and progress toward the skin, destroying the surrounding tissue prior to showing any signs at the skin level.

Treatment for pressure ulcers is a lengthy and costly process. Severe ulcers usually require surgery and an average hospital stay of 2 months, with costs ranging from US$15,800 to US$72,680 to treat each ulcer[2]. Just in North America alone this adds up to $2.2 to $3.6 billion[3] every year.

Current prevention techniques include the recommendation to perform frequent postural adjustments to relieve pressure from the tissues at risk of developing ulcers[4-6], as well as the use of specialized cushions and mattresses.

Unfortunately, over the years there has not been a significant reduction in the incidence rates of pressure ulcers with currently available prevention techniques[7,8]. This warrants the continuing need for alternative prevention methods, in particular for ulcers that develop in the deep tissue.

This study proposes the use of intermittent electrical stimulation (IES) applied to the muscles at risk of developing an ulcer. IES-evoked contractions would allow the muscle to reshape periodically, relieving pressure at the bone-muscle interfaces, restoring blood flow, and increasing oxygenation to the tissue. This would effectively prevent the formation of pressure ulcers.
2. METHODS

2.1 Induction of a deep pressure ulcer

An experiment to quantify the damage to the deep tissue caused by externally applied pressure was performed in 3 Sprague-Dawley rats. Under isoflurane anesthesia, constant pressure (210, 190, and 140 kPa) was applied to the quadriceps muscle (QM) from one hind limb of each rat (experimental limb). Pressure was applied by a 3mm indenter for a duration of 1 1/2 or 2 hrs. After the removal of pressure the rats were allowed to recover and the analgesic buprenorphine was administered. Twenty-four hours after the removal of pressure, both hind limbs from two of the rats were imaged with Magnetic Resonance (MR). The MR scanning was performed in a 3.0T magnet using a $T_2$ weighted spin-echo sequence. The volume of edema present in the muscle was estimated from the MR images. Subsequently, all rats were euthanized and both QM extracted (n=3). The weight and volume of each muscle from the experimental limb was compared against those from the contra lateral limb.

2.2 Effectiveness of intermittent electrical stimulation in pressure ulcer prevention

The effectiveness of IES in preventing the onset of deep pressure ulcers was tested in 18 Sprague-Dawley rats. The animals were divided into a Control Group (CG) and two Experimental Groups (EG1 & EG2) of 6 rats each. Under isoflurane anesthesia, constant pressure was applied to the QM of one hind limb (experimental leg) of every animal for 2 hours. The pressure was applied by a load equivalent to 38% of the bodyweight of each animal distributed over a 3mm diameter indenter. Prior to the pressure application all animals were implanted with a nerve cuff around the femoral nerve of both hind limbs. The experimental leg of every rat in EG1 and EG2 received a 10s stimuli bout (50Hz, 250µs, charge balanced, constant current) every 10 and 5 min respectively during the same time of pressure application. Rats in CG only received the pressure application. Twenty-four hours after the removal of pressure, an MRI of both hind limbs from every rat was performed to assess deep tissue damage to the experimental leg by quantifying the amount of edema present in it. The contra lateral leg was utilized as an internal control for each rat. Subsequently, the rats were perfused and the QM from both limbs extracted and prepared for histological analysis. The edema quantifications from MRI were corroborated by the histological assessment of the QM from the experimental limb of every rat. A necrosis score was given to each QM slide based on the area of the muscle exhibiting necrosis (0: none, 1: 0-10%, 2: 10-25%, 3: 25-50%, 4: >50%).

3. RESULTS

3.1 Induction of a deep pressure ulcer

Edema was successfully detected in both animals scanned. The difference in the volume of edema between the two rats can be observed in Fig 2A. The calculated volume (3-6 cm$^3$) corresponded well with weight and volume measurements obtained from the extracted muscles (compare Fig. 2A to Fig. 2B). The extent of swelling on each extracted muscle, represented by the % increase in weight compared to the contra lateral limb, was dependant on the amount of pressure applied to each rat. There were minimal signs of tissue damage on the internal part of the skin from one rat. The other two exhibited no marks at all.
3.2 Effectiveness of intermittent electrical stimulation in pressure ulcer prevention

The amount of edema present in the experimental leg of rats in CG was 52.69% on average with a standard deviation of 11.51%. This was significantly higher (p = 0.001, one-way ANOVA) than both EG1 and EG2, were edema was 15.24% (stdev=11.04) and 18.99% (stdev=11.51) respectively. There was no significant difference between EG1 and EG2. These MRI results were confirmed by the histological assessment, in which CG received an average necrosis score of 3.17. In comparison the necrosis scores of EG1 and EG2 were 1 and 1.17 respectively.

4. DISCUSSION AND CONCLUSIONS

The results in Fig. 2 showed that the application of external pressure for durations as short as 1 1/2 hrs. is enough to generate a significant amount of damage to the deep tissue. The extension of the damage seems to be closely related to the amount of pressure applied. We did find muscle to be more susceptible to ischemia than skin. This can be observed in the fact that the outside surface of the skin in all experimental limbs looked normal and provided no clues regarding the underlying edema in the muscle, even in the most severely affected animal (rat 1, Fig. 2).

The use of IES has shown a significant beneficial effect when applied to muscles exposed to prolonged periods of loading. Results obtained from both the MRI and the histological assessment of the deep tissue health, show that intermittent electrical stimulation can indeed reduce the amount of damage to the deep tissue, indicating it could be an effective prevention technique against the formation of deep pressure ulcers.

At the moment we have not yet determined if this beneficial effect is due to 1) an increase in the oxygenation of the tissue being stimulated; 2) due to the reduction of the internal pressure profiles during each contraction; or 3) to an equal contribution from both of these situations. Future studies will be focused in answering this question. At the same time, based on the findings regarding tissue oxygenation and the changes in internal pressure profiles, the stimulation parameters will be optimised to further reduce the amount of damage observed in the tissue. Accomplishing this will get us a step closer in our goal of finding an effective technique for the prevention of deep pressure ulcers.

References


Acknowledgements

These studies where done with the funding from the Canadian Institutes of Health Research and the Alberta Heritage Foundation for Medical Research.